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ABSTRACT

Field scale fertilizer tests on forage crops in Alberta indicate varying economic responses to nitrogen, phosphorus, sulfur and potassium fertilizers, either alone or in combination, depending upon moisture conditions, area and soils.

Besides producing yield increases, fertilizers have altered the chemical composition of the forage. Generally, they have increased the mineral and protein content, and in some cases they have decreased the crude fiber content.

Feeding trials, conducted with rabbits as experimental animals, have indicated that fertilized feeds have improved palatability and nutritive value. Rabbits fed fertilized forage have made faster and more economical gains than those fed unfertilized forage.

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THE UNIVERSITY OF ALBERTA

"SOME EFFECTS OF COMMERCIAL FERTILIZERS ON
YIELD AND QUALITY OF FORAGE CROPS IN ALBERTA"

A DISSERTATION

SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

FACULTY OF AGRICULTURE
DEPARTMENT OF SOIL SCIENCE

by

L. GAREAU, B.A. (Laval) B.S.A. (Saskatchewan)

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SOME EFFECTS OF COMMERCIAL FERTILIZERS ON YIELD
AND QUALITY OF FORAGE CROPS IN ALBERTA

L. Gareau

INTRODUCTION

During the past 10 to 15 years, the practice of using commercial fertilizers has been readily accepted by a large number of farmers in the Prairie Provinces. Sales of fertilizers are expanding greatly, but in most areas a very small proportion of the increase is being directed to the fertilization of forage crops. Since the production of forage is taking a more and more important place in the program of Western Canadian Agriculture, it is desirable to have more information concerning the responses of grass and legume crops to the application of commercial fertilizers.

A great number of fertilizer trials have been carried out on Alberta crops. The Provincial Advisory Fertilizer Committee has prepared and published definite recommendations for fertilizer use on grain for the various soil zones of the province (17). This publication also suggests rates of application and types of fertilizers for use on forage crops. These suggestions are based on data obtained by the Department of Soil Science, University of Alberta, and by the Experimental Stations in the province, at a few permanent test locations and by a limited number of co-operative trials. To date, it is difficult to evaluate the actual economics of fertilizing

forage crops other than legumes on sulfur-deficient soils; it is therefore easy to understand why Alberta farmers are hesitant to adopt the practice more generally.

With the passing of pioneer farming in the older settlements of the province and with the adoption of a more balanced type of agriculture, there is a definite trend towards seeding to forage crops greater and greater acreages of the grain farm. High priced lands, close to cities and milk shed areas, are now requiring a more intensive type of farming and thereby urgently call for more specific information concerning fertilization of forage crops.

The situation in the grey wooded soil areas of the province is different. These soils are being developed at a rapid pace, but will not produce profitable grain crops, except in rotation with legumes. The fertilizer experiments carried out at Breton during the last 25 years have proven beyond any doubt the value of forage fertilization for sulfur-deficient soils. However, many farmers still ask what kind and rate of fertilization is most profitable on these soils. To answer this question, the effects of fertilizers on quality as well as on yield of forage must be ascertained.

Results of chemical analyses and microbiological assays show considerable differences in the quality of both grain and forages produced on fertilized and unfertilized soils in the province. Preference of cattle for fertilized forage plots has been observed by both farmers and agrologists. Feeding trials with rabbits, carried out by the Department of Soil Science, University of Alberta, in 1951,

showed greater gains per unit of feed consumed by animals fed fertilized hays than those fed unfertilized hay taken from the same field at the same time. (See Appendix, Tables 14 to 17) However, to date no data have been published on the effects of fertilizers on the quality of Alberta forage crops, as determined by bioassays or feeding trials.

Biological assays, carried out in other countries, have shown that increased yields as bushels or tonnages per acre may not accurately evaluate agronomic products in terms of their value for the sustenance of animals (46). When the chemical composition of feeds was changed by different soil treatments, the animal response was not correlated closely enough to warrant the acceptance of the chemical analysis as an index of nutritive value. Fertilization may not always give feed of improved nutritive value, even when increases in yields are obtained. This suggests that to obtain maximum feeding value of forages the plant nutrients have to be present and available in the soil in the proper ratios.

The project being reported on was undertaken to obtain information on some of the foregoing points. There were two general objectives:

1. To obtain more information concerning the yield increases which can be expected from the use of commercial fertilizers on forage crops grown in certain areas of the province.
2. To obtain some information concerning the effects of fertilizers on the feeding value of forage crops responding to fertilization.

REVIEW OF LITERATURE

Grain crop yields in Western Canada.

The effects of fertilizers on the yields of grain crops in the Prairie Provinces have been studied extensively during the last 30 years. In 1936, Wyatt (52) reported favorable responses of grain to ammonium phosphate, 11-48-0, on the black soils and to 16-20-0 on the grey soils of Alberta. Ten years later Mitchell (33) indicated economic increases in yield of wheat from the application of 20 to 40 pounds of 11-48-0 on summerfallow land in the dark brown, black and grey wooded soil zones of Saskatchewan. McIsaac and McGregor (31), in 1941, showed that significant yield increases of flax could be obtained by the application of 20 pounds per acre of 11-48-0 in Northern Saskatchewan and North Eastern Alberta. Anderson (4), working with grains on soils of the Peace River District of Alberta and British Columbia, found these soils all responsive to phosphatic fertilizers even when the phosphorus content of the soil was high. The responsiveness of Peace River soils to phosphorus may be related to the geology there. In 1951 this worker reported that ammonium phosphate, 11-48-0 at 40 pounds per acre increased yields by an average of five bushels per acre per year. Moreover, fertilizers promoted stronger root development with consequent better tillering and stands, and they hastened maturity by three to five days.

The foregoing workers as well as numerous data published by Universities, Experimental Stations and Departments of Agriculture in the Western Provinces (Fertilizer Advisory Committee Reports) have proven the economic importance of ammonium phosphate fertilizers on grain crops in all regions of the Canadian Prairies where favorable

moisture conditions exist. Usually, the most profitable increases are obtained during the years of most favorable moisture conditions.

Effects of fertilizers on forage crop yields.

The use of large quantities of commercial fertilizers is recognized as standard practice in the management of forage crops in all parts of the world where an intensive type of agriculture has been attained (24). Any issue of a farm journal, for example "The Country Gentleman," will contain ample evidence of the importance of proper fertilization of hay and pasture in the United States. Scientific papers on the subject are also enlightening, and reveal many important yield increases from nitrogen, phosphorus, potassium, and sulfur, either singly or in combination, in other countries and in Canada.

Large increases in yield have been reported in some other countries. Chamblee et al.(11), in North Carolina, found that the addition of 200 pounds per acre of nitrogen increased the yield of forage by 689 pounds, while Harper (19), in Oklahoma, in 1953 reported trebling of forage production by growth of soil building legumes with proper fertilization. Although the latter was mainly testing phosphatic fertilizer effects on small grain winter pastures, it is interesting to note that the greatest amount of forage and protein per acre produced was with a four-year rotation including sweet clover, a legume recognized for its ability to serve as host for the symbiotic nitrogen fixing bacteria. In Great Britain, Stewart and Holmes (49) reported that heavy dressings of nitrogen increased enormously both the yield of dry matter and the percentage of crude protein in it. Moreover, they found a strikingly positive nitrogen-potassium interaction and very high yield increases of

grass herbage by the addition of potassium fertilizer. From a pasture experiment at the West Virginia Agricultural Experiment Station, carried out in the early 1930's, Pierre (40) reported increases of alfalfa herbage of 54% during the first year and 37% during the fourth year after the application of 500 pounds of superphosphate per acre. Black et al. (8), in an experiment conducted from 1941 to 1945 in the nearly flat coastal plains of Texas bordering the Gulf of Mexico, found that an application of 200 pounds of triple superphosphate per acre increased the grazing capacity of range land by 50%. Rost et al. (45), in Minnesota, reported that for the four-year period 1942-1945, hay fields fertilized with superphosphate gave average increases in yields of 1.01 tons of hay per acre. Matrone et al. (30), in North Carolina, obtained two to three-fold increased yields of soybean forage by the application of phosphatic fertilizers. At the Forest and Range Experiment Station of Colorado, Retzer (44) obtained good responses not only to nitrogen and phosphorus but also to potassium on soils where a chemical analysis showed a deficiency in one or more of these elements. Significant yield increases of herbage were shown also by Newosad (37), in the Eastern Townships of Quebec, by the application to permanent pastures of combinations of calcium, nitrogen, phosphorus and potassium. Bentley and Green (5), studying the use of commercial fertilizers to improve the California foothills range, found that the sulfur bearing fertilizers were of particular value in improving the annual plant forage on the soils of granitic origin. The response to sulfur, although delayed during the first year of application, was shown first on the native clovers, followed in the second year by increased production of both grass and clovers, and a residual response in these plants during the

third year. Average increases of 900 pounds per acre per year were reported following an application of 60 pounds of sulfur every three years at a cost of \$2.50 to \$4.00.

Considerable yield data are available concerning the effects of commercial fertilizers on forages in Western Canada. Knowles and Cooke (23), in Saskatchewan, tried several nitrogen fertilizer treatments on brome grass in the dark brown and black soil zones. They found that an application of nitrogen in the form of ammonium nitrate increased yields by one ton of forage per acre, or by 100 pounds of seed per acre, under favorable moisture conditions. However, in years of limited rainfall, the application of nitrogen failed to give satisfactory yield increases. Since the fertilizer was applied both in the spring and in the fall, and since ammonium nitrate is readily soluble, it would appear that the effects of this fertilizer were limited by the moisture conditions during the growing season. This observation is in accordance with the principle of transpiration ratio, which, as outlined by Lyon et al. (24), limits production of dry matter, especially under the more arid climates.

Wyatt (52), in 1936, reported hay responses to nitrogen, phosphorus and sulfur applied to the grey wooded soils of Alberta. Some workers, since, have failed to find any response to fertilizers for forage crops on certain areas of the Grey Wooded Soil Zone even when moisture conditions were not the limiting factor. Anderson (4), in 1950, stated that no significant yield increase had been obtained in fertilizer trials on forage grown in the Peace River District. Elsewhere in Alberta, the greatest fertilizer effects have been obtained on the grey wooded soils and the most spectacular yield increases have been connected with sulfur bearing fertilizers. As early as 1936, Newton (35) noted

large increases in growth of red and alsike clovers from the application, in field plot tests, of 100 pounds per acre of alkali salts containing a mixture of sodium, magnesium and calcium sulfates. Kenwood (21), in 1947, and Newton et al. (36), in 1948, reported varying yield increases from the application of different fertilizers to the Breton Plots, for the three-year period, 1944-1946, and the 17-year period, 1930-1946. They stated that responses obtained by the application of one or both of nitrogen and phosphorus were not great, but significant yield increases and satisfactory yields of legumes were obtained whenever sulfur was included in the fertilizer, either alone or in combination with other elements. Spectacular average yields of two and one half tons of hay per acre for the better fertilizers were obtained in comparison with an average yield of one half ton per acre for the check plots receiving no fertilizer. Some of their data are summarized in tables 18 and 19 of the appendix. It is worth noting that all fertilizers containing high percentages of sulfur gave large increases in yield of legumes such as clovers and alfalfa, while the high nitrogen fertilizer, ammonium nitrate, which contains no sulfur, gave unsatisfactory results for the rates used at Breton. Sulfur thus seems to be the main limiting element for the production of legumes in the Breton area. The authors concluded that, on the grey wooded soils, West of Edmonton, it was possible to maintain high yields of clover over a long period of years and even increase the yields by the use of suitable fertilizers and management.

Newton et al. (36) also reported on a number of co-operative experiments under field conditions in the Breton, Cherhill, Fallis and Carrot Creek areas. The authors concluded that it was generally more profitable to apply fertilizers to legumes than to grain crops on these

grey wooded soils, and that there was a marked sulfur deficiency as far as legumes were concerned in the areas noted. This fact was again demonstrated by Hoff (20), in 1951 and 1952. Working with radioactive sulfur on various grey wooded soils of Alberta, he obtained yield increases of legumes as high as 300% in response to fertilizers.

Results of co-operative trials on forage, conducted and published under the direction of the Alberta Fertilizer Advisory Committee for the period 1949-1954 are reported in the annual A.F.A.C. Reports. Since these data have not been summarized elsewhere, they have been tabulated and presented in tables 20 to 25 of the appendix.

Effects of fertilizers on quality of crops.

Some ardent believers in the organic theory of soil fertility have attempted to discredit the value of chemical fertilizers in the improvement of the quality of crops. Sykes (50), in Great Britain, said: "Every farmer knows that he cannot farm for ever without organic replacement." He claimed that the produce obtained, through the application of composts were more life sustaining, more healthful, and more palatable than the chemically fertilized crops. No one will question the importance of humus and the so-called "natural" fertilizers in the production of profitable and high quality crop yields. "There is, however, little or no evidence to support the claim for superior quality of crops by avoiding chemical fertilizers." (15). It is difficult to prove any betterment of quality resulting from fertilization, since quality in feeds is largely determined by soil, season, and variety of plants. "Fertilizers, where needed, not only increase crop yields, affect time and degree of maturity, but also may raise protein content, alter proportion of plant

species and, under certain conditions, also alter the mineral composition of crops. Moreover, commercial fertilizers are not destructive of vitamins and other constituents of feed " (15).

Fertilizers have been shown to have a variety of effects on quality. Albrecht (1) reported that the protein of wheat had been stepped up 90% by a number of successive applications of nitrogen fertilizers on some soils in Missouri. Newton et al. (36) obtained higher protein in wheat and barley and higher baking quality of wheat grown with fertilizer at Breton.

Cases of cattle poisoning, which occurred in Southern Saskatchewan in 1942, have been blamed on the accumulation of nitrates in oat straw. Investigating the problem, Doughty and Warder (14) found that potassium nitrate, applied to pots in greenhouse experiments, did increase the content of nitrate in oat straw to a point of being detrimental to the quality, if this treatment was combined with drought conditions at the time of heading and ripening. However, under field condition, with recommended fertilizers on forage crops, it is unlikely that any toxic amount may accumulate. It emphasizes, nevertheless, the importance of proper balance in the fertilizer elements in order to produce an ideal feed.

Effects on botanical composition.

There is ample literature dealing with the effects of commercial fertilizers on the forage botanical composition which directly affects the quality of herbage produced. Chamblee et al. (11), in North Carolina, reported that yields of orchard grass and Dallis grass in permanent pastures were increased by summer application of nitrogen while that of

white clover was temporarily reduced. Pierre (40) stated that, on the West Virginia phosphorus-deficient soils top-dressed with phosphorus, Kentucky blue grass and white clover would crowd out the poorer plants. Nowosad (37), in Eastern Canada, cited dozens of references to work carried out on the subject in many parts of the world during the last 100 years. He, himself, found that, in the Eastern Townships of Quebec, lime had increased the proportion of grasses and decreased the proportion of clovers. Similar conditions were found by Bentley and Green (5) in the California foothills range, where sulfur would temporarily increase the percentage of the clover species.

Effects on mineral composition.

The chemist is reluctant to accept the change in the botanical composition of crops as the only factor affected by fertilizers and controlling the quality of forage crop mixtures. For this reason, most of the workers already cited have also carried out determinations on the chemical composition of the herbage grown with and without fertilizers. Chamblee et al.(11) showed that the nitrogen content of orchard grass and white clover was increased four to six weeks after the application of 100 pounds of nitrogen fertilizers. Dobby et al.(13) found that the application of nitrogen, in a complete fertilizer at seeding time, increased the nitrogen content of the first clipping of forage; additional top dressings increased the nitrogen content in further clippings. Prince (41), in South Carolina, reported that an increase in the number of top dressings of nitrogen increased the nitrogen, phosphorus and potassium content of the forage, and indirectly decreased the calcium and magnesium content. Fudge and Lancaster (18) made analyses on Bermuda and carpet grass which had been fertilized with 100 pounds of phosphoric acid; there was a considerable increase in phosphoric acid content.

Harper (19) claimed that the calcium and phosphorus content of forage had been kept well above the minimum safety levels by phosphate fertilization, while the same forage grown without fertilizer on the same type of soil often contained these minerals in a quantity below the recognized safety level. Matrone et al. (30) found that low levels of soil phosphorus brought about changes in the chemical composition of soybean forage; raising this phosphorus level lead to increasing the phosphorus, calcium and protein content of the forage. Black et al. (8) discovered that the phosphorus content of samples, taken from pasture fertilized with phosphate, was for the most part higher than for the unfertilized pasture, while the protein and phosphorus content was closely associated with rainfall, being lowest during the winter and the drought periods.

Analytical data on forages in Western Canada are few. Ellis and Caldwell (16) concluded that the mineral content of Manitoba hays depend on soil, plant species, climate, seasonal variation, stage of maturity, and, in some cases, fertilizers. They suggested that phosphate fertilization, where giving yield increases, raised the phosphate content of the hays. Kenwood (21) showed that, on the grey soil of Breton, fertilizers had more effect on the nitrogen content of the clover hay than did seasonal variations. Yet, the fertilizers containing only nitrogen did not increase the nitrogen content of the crop on that soil. Newton et al. (op. cit.) stated that in terms of digestible nutrients, the better plots of clover and grain rotation systems at Breton are twice as productive as the better plots of the continuous wheat system. Some fertilizer treatments have increased the protein content of the legume hays, thus making them better feeds on a pound for pound basis than the unfertilized hay. The work of Hoff (op. cit.) has given very striking data relative to the effects of sulfur fertilization on the

chemical composition of legumes in the grey wooded soils of Alberta. The percentage sulfur determined varied from a low of 0.08% for the check plots to a high of 0.42% for treated plots, with an average of 0.15% for check plots and 0.23% for treated plots. In most cases the nitrogen content of the legumes was also considerably increased by the application of the sulfur fertilizers.

Effects on feed quality determined biologically.

The quality of the protein contained in feed may vary considerably. The actual make-up of a protein, which cannot be determined by the usual chemical methods, is more easily analyzed by microbiological assays. Using this type of determination, Renner et al. (43) found that increases in percentage protein of grain were associated with some decrease in quality as measured by the percentage that nine essential amino-acids contributed to the protein. However, this decrease in quality was less marked in grain from rotation plots to which fertilizers containing sulfur had been applied, than in those from plots treated with fertilizers that did not supply sulfur. Microbiological assays are not so conveniently performed on forage feeds. Nevertheless, there is reason to believe that fertilizers have in some cases a beneficial effect on the make-up of the proteins of forages. In any event, the ultimate criterion of feed value is undoubtedly demonstrated by animal response.

Many modern workers in the United States have been trying to estimate the final value of fertilization by means of feeding trials. Browne (9), studying some relationships of soil to plant and animal nutrition, reported injurious effects from high "magnesian" soils on plants and animals. He also found a definite correlation between phosphorus deficiency in soils and osteomalacia in cattle. Morrison (34) in 1950, stated that under present conditions farm animals suffer from a

deficiency of phosphorus and calcium much more frequently than in the early days, because the supply of minerals in feeds has decreased in the older farming districts, following the soil depletion of calcium and phosphorus. He also mentioned the greater requirements by animals today because rate of production of milk and meat has been increased through improved methods of feeding and management.

The phosphorus content of forages affects their nutritional value. Madsen (28), writing on the nutritional diseases of livestock, claimed that aphosphorosis is directly connected with the inadequacy of phosphorus in the soil. He supported the theory of McIntosh that alfalfa grown on fertile soils will cause less bloating than alfalfa on run-down soils. Rost et al. (45) said that soils well supplied with organic matter and available mineral elements produce high quality crops in so far as feeding value is concerned, while run-down and infertile soils produce less palatable and nutritious feeds. Some Minnesota farmers purchase feeds from fertile areas because their livestock make more rapid and profitable gains than on the same type of feeds from poorer areas. Fertilizer trials carried out by these workers revealed that the application of superphosphate to alfalfa hay in Minnesota has resulted in the disappearance of phosphate deficiency.

The experiments of Black et al. (8) in Texas, on the methods of supplying phosphorus to range cattle, have given very strong evidence of the value of fertilizers on the nutritional improvement of forage. Three groups of range cattle were grazed on unfertilized native range: Group I receiving no additional phosphorus; Group II having access to bonemeal in well distributed self feeders; Group III being supplied phosphorus through the use of disodium phosphate dissolved in the

drinking water. A fourth group grazed range fertilized in 1941 with 200 pounds of triple superphosphate per acre. After five years the data and observations were summarized as follows:

- a) The cows in Group II and Group III, grazing on unfertilized pasture but receiving mineral supplements, produced fairly constant and normal calf crops; they kept in excellent condition throughout the experiment. The net returns for the five-year period were \$3.60 per acre for Group II with the bonemeal, and \$3.73 per acre for Group III with the disodium phosphate.
- b) The cows in Group I, grazing on unfertilized pasture and receiving no supplemental phosphorus, showed signs of aphosphorosis and their blood content of inorganic phosphorus was seldom above 4 mg. per 100 ml., which is considered the minimum level for cows not showing signs of phosphorus deficiency.
- c) The cows on fertilized range maintained a high blood phosphorus level during the first year of experiment, but showed a downward trend afterwards, reaching a dangerous low level by the fifth year.
- d) The cows on fertilized pasture produced a much greater percentage of calves with significantly heavier weaning weights. Pasture fertilization increased the calf crop by 42% and 208 pounds of weaned calf weight per cow per year; it increased the weaned calf weight per acre by 128%.
- e) With weaned calves valued at 15¢ per pound, and after deducting the cost of fertilizer and fertilizer application, the fertilized range returned, on the average, \$48.69 per cow or \$4.29 per acre compared to \$38.34 and \$2.50 per acre for the unfertilized range.

Smith and Albrecht (46) conducted a study of feed efficiency in terms of biological assays. They concluded that the addition of phosphorus and calcium to deficient soils increased the efficiency of

forage fed to lambs, and differences varied more widely than the protein and mineral content of the feed would indicate. Not only the rate of gain, but also the wool quality of the animals fed the fertilized forage was increased. In contrast, the addition of fertilizers, which brought about unbalanced nutrient conditions in the soil, lowered the feeding efficiency of the crop. Thus, timothy hay having received an excess of nitrogen, alfalfa, an excess of lime or phosphorus, or soybean grown on soil deficient in potash through excessive liming, produced a crop lower in nutritive value than the unfertilized crop, even though yields had been increased by the fertilizer treatments.

Matrone et al. (29) obtained increased nutritive value of fertilized soybean forage, as indicated by growth of lambs, growth and bone formation of rabbits. These effects resulted from phosphorus fertilization, but there was no evidence of change in phosphorus and protein content of the hay. McLean et al. (32) also found some differences in rates and efficiencies of animal gains on feeds from different soil types with and without fertilizer treatments. Studying various properties of bones of rabbits, they arrived at the following conclusions:

- a) Fertilizer treatments tend to obscure the effects of soil type upon plant yield and composition, and these in turn tend to obliterate differences as measured by animal response.
- b) Production as animal products is a matter of balanced soil fertility.
- c) Gains in animals, like yields of hay, do not give the entire picture of fertility.
- d) Varied physiology in plants is shown in part by chemical analysis, but more forcefully by bioassay.
- e) Varied physiology in animals is indicated by varied rates of animal gains and efficiency of gains, but is more forcefully demonstrated by

bone differences.

How long do the effects of fertilizers last? Much greater residual effects of commercial fertilizers on yield increases have been measured by forage crops than by grain crops. But yield increases do not give the complete story. While palatability is not in itself a measure of feed value, it is nevertheless a most important factor in the field of nutrition. "Forced fasting or insufficient total digestible nutrients in a diet is the most common fault of feeding and cause of deficiencies " (15). Preferential grazing of fertilized pastures and preferential feeding on forage from fertilized hay fields would therefore be an indication of some beneficial effect from fertilization. Albrecht (2) in Missouri has thus been able to answer at least part of the question by determining that cattle had shown preferential feeding on hay stacks from fertilized meadows eight years after treatment. Preferential grazing of the fertilized area was observed for at least nine years following fertilization.

It is evident that there is a need for correlation of physical units of soil classification with functional units in terms of crop and animal production as a means of measuring many factors operative in soils in their service to Agriculture. It is also evident that, by varying the levels of available nutrients in the soil, a change in the nutritional quality of a specific nutrient, with or without change in its quantity, may be brought about.

OUTLINE OF INVESTIGATION AND MATERIALS

Field scale fertilizer tests were conducted in 1954. Samples were taken for three types of determinations:

- a) Yield. Statistical analyses were made.
- b) Chemical analysis. The main mineral constituents were determined.
- c) Biological assays. Rabbits were used as experimental animals.

Locations and yields for the 1954 forage fertilizer tests are shown in tables 20 to 25 of the appendix.

Bulk feeds for the feeding trials were obtained from the following locations and treatments:

<u>Foley's farm</u> , Bonnyville:	Check
	$(\text{NH}_4)_2\text{SO}_4$ @ 140 lb./ac.
(Alfalfa-Brome-Fescue)	16-20-0 @ 360 lb./ac.
	10-32-10 @ 225 lb./ac.
<u>Ballhorn's farm</u> , Wetaskiwin:	Check
	33.5-0-0 @ 180 lb./ac.
(Alfalfa-Brome-Timothy)	16-20-0 @ 360 lb./ac.
	10-32-10 @ 225 lb./ac.
<u>Breton Plots</u> 1954:	Check
	11-48-0 @ 50 lb./ac.
(Altaswede clover)	Gypsum @ 500 lb./ac./5 years.
	0-20-0 @ 110 lb./ac.
<u>Breton Plots</u> 1952:	Check
(Altaswede clover)	Composite from 3 fertilized plots.

Athabasca Substation 1952:

Check

Sulfur @ 20 lb./ac.

(Altaswede clover)

16-20-0 @ 100 lb./ac. + S @ 6 lb./ac.

16-20-0 @ 100 lb./ac. + K_2SO_4 @ 40 lb./ac.

Botanically pure samples selected by hand were also taken in connection with the bulk feeds at the following locations:

Foley's, Bonnyville: Alfalfa and Brome.

Laporte's, Bonnyville: Sweet Clover.

Ballhorn's, Wetaskiwin: Alfalfa, Brome and Timothy.

Breton Field: Altaswede leaves and Altaswede stems.

Field soil samples for quick tests were obtained from the farms of Dery, Turcotte, and Dumont of Bonnyville. Two profile samples were also taken for quick tests near the Laporte and Sylvain farms, in the Muriel Lake district, South of Bonnyville.

Rabbits for the feeding trials were purchased from the Department of Animal Science, University of British Columbia.

METHODS

Fertilizer trials.

Field scale fertilizer trials were located on established stands of hay crops in the Bonnyville district. The work was done in co-operation with the Department of Soil Science, University of Alberta, which supplied the necessary equipment and some assistance. The fertilizer was applied broadcast with a standard fertilizer attachment carried on the end-gate of a half-ton truck, and driven by a belt from a pulley attached to the rear wheel of the truck. The strips or treatments were eight feet wide and on the average 1,000 feet long. The samples were taken at the normal hay-cutting stage of maturity.

For yield determinations, the hand sickle or a 36-inch power mower was used. When using the hand sickle, a square yard sample was taken at eight to ten successive spots in each strip, and with the power mower a three-square yard sample, also at eight to ten places in each strip. Individual samples were weighed green on a dairy scale. Green samples from the heavy and light yielding strips were air-dried and then reweighed to determine the moisture content of the crop. The sample weights were finally averaged for each treatment and the yields were expressed as tons per acre of cured hay. An analysis of variance was done on the data using the randomized block design. In cases where the results indicated that the difference between treatments approached significance by the analysis of variance, a t-test was also made.

Bulk feeds for bioassays.

Where spectacular yield increases occurred in rather uniform weed-free fields, some bulk feeds were collected for feeding trials.

A 36-inch wide swath was cut with the power mower down the centre of the strip concerned. Samples sufficient to give about 100 pounds of dry hay were cut from each desired treatment. The forage was raked by hand-rake and fork, picked up and carried away for curing. The curing process proved very difficult in 1954 since it had to be done under extremely wet conditions and it is possible that some spoilage may have occurred. Samples were ground and mixed by putting them through a John Deere combination feed cutter and hammer mill with a 1/8-inch sieve. Cut feed was blown through a revolving mixer, the feed being collected from the mixer into jute bags. These feeds were processed into pellets 7/32 inch in diameter by the North West Feed Mill pelleting machine. The pellets themselves were thoroughly mixed by pouring 16 to 20 times from one large (15-gallon) container to another. Approximately one pound of pellets was withdrawn for chemical analysis. This was done with a 1 1/2-inch bore brass tube inserted at five to six places in the container.

Hand selected samples.

Single plants of individual species of crops were taken by hand at intervals and at random throughout the entire treated strip in order to make up a pure botanical sample of about one pound green weight. The samples were taken to the laboratory, air-dried and finely ground, using a Christie and Norris Laboratory Mill, Size 8.

Soil samples.

Surface, 0-6 inches, and subsurface, 6-12 inches, samples were taken with a one-inch diameter core sampler. Two sets of profile samples by horizons were taken from freshly exposed road cuts adjacent to the Sylvain and Laporte farms.

Soil analysis.

The Beckman pH meter was used to determine the pH of all soil samples. "Quick" tests for nitrates, phosphorus, potassium, calcium, magnesium, and sulfates were also carried out using the Spurway methods (47).

Feed analysis.

All feed samples were analyzed on oven dry basis for the following elements: nitrogen, phosphorus, potassium, sulfur, calcium, magnesium, and sodium. Six pelleted samples were also analyzed for crude fiber. Nitrogen was determined by the Kjeldahl-Gunning method (38) (51), using selenium as a catalyst, and 4% boric acid containing methyl red-bromocresol green indicator to receive the ammonia distillate which was back-titrated with 0.0728 normal sulfuric acid (38) (42). All determinations were in duplicate, using one-gram oven dried samples. To check the accuracy of the sampling of the bulk feeds, a second nitrogen determination was run in duplicate on six samples of pellets. These materials were thoroughly mixed a second time in a mixing tray, quartered down to a one-pound size, reground in a Wiley Mill, and remixed on a large square of paper. Other determinations were made on extracts obtained by wet ashing the plant materials, using the nitric-perchloric acid method outlined by Hoff (20). Sulfur was determined by turbidimetry on a Beckman Model DU spectrophotometer, using the method developed by Schroer and Bentley as outlined by Hoff (20). Phosphorus was determined by colorimetry on the Bausch and Lomb Monochromatic colorimeter, using the meta-vanadate method described by Kitson and Mellon (22). The procedure followed is given in full detail in the appendix. The versene method developed by Bentley was used to

determine magnesium volumetrically, while calcium was determined both by the potassium permanganate method (51), and by difference using versene. The procedure for calcium and magnesium determination by versene is given in detail in Pawluk's thesis (39). Sodium and potassium were determined on the Model DU Beckman spectrophotometer using the oxygen-acetylene flame. This method for plant analysis is recommended by DeLong et al (12). Details of procedures are given in the appendix.

Crude fiber determinations were carried out on the six samples of bulk feed pellets which had been remixed and reground for the check on nitrogen and sampling error. The method was the one in use by the Department of Animal Science, University of Alberta. It is described briefly in the appendix.

Feeding trials.

The experimental animals for the bioassays were housed in the rabbit room of the Department of Animal Science. This room was air-conditioned, with temperature and humidity controls. During the course of the experiments, the temperature was set at 70 degrees F., and the relative humidity control at 'medium.' Darkness was provided in the room from approximately 10:30 o'clock p.m. to 7:30 o'clock a.m.

Two types of feeding trials were carried out on the bulk samples: tests of efficiency and tests of palatability.

For palatability determinations, four rabbits of the same sex were placed in a large cage, 36" x 48" x 24", and were allowed to feed ad libitum on the feeds being tested. Feeds, along with water and salt, were kept constantly in front of the rabbits. Two or four feeds were

tested at a time, there being two bowls of each feed placed at random in the cage. Weights of feed consumed were recorded.

For the feed efficiency trials, weanling rabbits, sibs or cousin sibs, seven to nine weeks old were used. Upon arrival, the animals were placed in wire cages 24" x 16" x 14" in size. One or two rabbits to a cage proved satisfactory. All rabbits were fed for the first six days on the same diet of commercial rabbit pellet feed. Water was kept in front of the animals at all times, either in bowls or in automatic fountains. A small block of iodized stock salt was also kept secured on the wall of the cage, throughout the experiment. Weights were taken and recorded daily during this first period, at 8:30 o'clock a.m. After six days, the animals were allocated to groups corresponding to the feeds to be tested. Care was taken to obtain representative animals in each group, similar in genetical make-up, sex, average weight, rate of growth and performance. The groups were placed at random on the feeds to be assayed.

Rabbit weights were recorded daily for the first three days of the efficiency tests, and every two days afterwards. Since the rabbit weights varied considerably from one weighing to the next, it was found more satisfactory to use as original weight the average of the last three weighings before the start of the experiment. Similarly, the average of the last three weighings before the end of the feeding period was adopted as the final weight.

An attempt to record the feed consumed by the rabbits in each cage was also made. The accuracy of these records was variable. It was found that some rabbits, especially on the less palatable feeds, spilled

a considerable amount which could not be accurately recovered. Therefore, only estimates of consumption could be made in some cases.

Weight-gain data for the various feeding experiments were subjected to an analysis of variance.

It has already been mentioned that not all samples used in this study came from the Bonnyville district. Some materials came from the Breton plots and some came from the Canada Department of Agriculture Sub-Station at Athabasca. One set of materials came from the Roy Ballhorn farm near Wetaskiwin which is located on Wetaskiwin black loam. Procedures used with these materials were all identical to those described with one exception. The 1952 altaswede material from Breton was hand-picked to be free of weeds and any other extraneous materials.

Hemoglobin determination.

The rabbits from the Athabasca feed trial were tested for hemoglobin. The oxyhemoglobin method, which is used by the Department of Animal Science, was followed for this determination.

This is Evelyn's method which is described in the Journal of Biological Chemistry, Volume 115.

RESULTS

Field trials.

The results of the 1954 field scale fertilizer trials are all contained in the tabulation of the co-operative fertilizer tests, in the appendix. However, since the author was particularly interested in the Bonnyville district, a summary of seven trials has been prepared and is presented in Table 1.

As shown in Table 1, some very outstanding yield increases were obtained from the application of commercial fertilizers in the Bonnyville area, during the 1954 season. All fertilizers, except 33.5-0-0, generally gave highly significant responses. This indicates that phosphorus and sulfur, applied to forage crops in the Bonnyville district, are capable of materially increasing the crop returns.

The nitrogen fertilizer alone, applied as nitraprills (ammonium nitrate 33.5-0-0) increased the yield significantly in only two cases out of the seven plots and a second cut on two of the plots. One of these increases occurred on the black soil at Dery's. At Foley's, on a grey soil, where nitraprills also gave a significant yield increase, a very striking effect from the nitrogen fertilizer was noticed. The nitraprills treatment was placed next to the ammonium sulfate, 21-0-0, fertilized strip, and, where the two treatments had overlapped, a strip of hay six to twelve inches wide was conspicuously taller, ranker, and greener throughout the length of the field. This phenomenon was probably due to the fact that in some cases a minimum or threshold level of nitrogen is necessary to produce a yield increase. Since 21-0-0 in that field gave

TABLE 1.

RESULTS OF 1954 TESTS ON FORAGE CROPS IN BONNYVILLE DISTRICT

Farmer's name	Yield of check, tons/ac.	Increases due to fertilizer treatment, tons per acre							M.S.D. to compare fertilizer with		
		11-48-0 @		16-20-0 @		33.5-0-0 @		10-32-10 @		Fert.	Check
		75#	150#	180#	360#	180#	225#	@	140#		
Dery	1.5	0.8*	1.1*	1.1*	1.4*	0.6*	1.6*	0.7*	0.3	0.4	0.3
" 2nd cut	0.8	0.7*	1.2*	0.8*	1.0*	0.1	1.3*	0.3*		0.3	
Dumont	1.9	0.6	0.8*	1.3*	1.5*	-0.4	1.4*	1.5*		0.6	0.5
Foley	1.5	0.5*	0.8*	1.2*	1.8*	0.4*	1.1*	1.5*		0.4	0.3
Laporte	0.6	0.7*	1.0*	1.1*	1.1*	0.1	1.8*	1.5*		0.4	0.3
Turcotte	1.8	0.5*	0.7*	1.3*	1.7*	0.4	1.8*	1.2*		0.5	0.4
" 2nd cut	0.9	0.2	0.6*	0.7*	0.9*	0.1	1.1*	0.7*		0.3	0.2
Verrier	1.5	1.1*	1.5*	1.8*	2.1*	0.2	1.7*	1.5*		0.6	
Sylvain	(not sampled)										
7-field aver.	1.5	0.7	1.1	1.3	1.6	0.2	1.7	1.3			

* Significant yield increase.

Note: Soil at the Dery farm is black. The soil at Turcotte's and on part of the Dumont field is degraded black. Other soils are grey wooded and are developed on glacial till parent material.

a highly significant yield increase, another possible explanation of the phenomenon is that nitrogen did not have its optimum effect until the plants' need for sulfur had been satisfied.

The data suggest a response to potassium. In five out of eight crops harvested, the complete fertilizer, 10-32-10, has given the largest yield increase. The average yield for the 10-32-10 treatment was slightly above the second highest yielding treatment (16-20-0) which supplied, at the rate of 360 pounds per acre used, the same amount of phosphate but considerably larger amounts of nitrogen and sulfur than 10-32-10 applied at the rate of 225 pounds per acre.

The poor crop growth on the Sylvain farm made it impossible to obtain yield samples from the trial. It is difficult to explain the lack of visual response to fertilizer treatment on this farm located approximately six miles from either Foley's or Laporte's, when spectacular yield increases were obtained on the latter two farms.

From an economic standpoint, Table 2 shows that ammonium sulfate, 21-0-0, has given the most profitable increases of all the treatments used. It is assumed in this table that no difference in feed value was obtained by the fertilizer treatments.

Soil analysis:

The field soil samples analyzed in Table 3 were taken from farms in the Bonnyville district where the soils varied widely in the color of the cultivated layer. However, analyses show that available plant nutrients vary little. The field soils all showed a definitely low phosphorus availability, which is in agreement with their high response to phosphorus fertilization. The failure to detect nitrates and sulfates is an indication that nitrogen and sulfur fertilizers may also be beneficial. The chemical data for these soils are in very good agreement with the results obtained by the Department of Soil Science on farmers' samples sent in for testing.

TABLE 2.

1954 AVERAGE RETURNS FROM FERTILIZERS ON FORAGE IN BONNYVILLE AREA

<u>Treatment</u>	<u>Aver. yield increase, t./ac.</u>	<u>Value of feed* @ \$15.00/ton</u>	<u>Approx. cost of fert. application</u>	<u>Profit</u>
11-48-0 @ 75# @ 150#	0.72 1.10	\$10.80 16.50	\$ 4.50 9.00	\$ 6.30 7.50
16-20-0 @ 180# @ 360#	1.33 1.64	19.95 24.60	8.10 16.20	11.85 8.40
33.5-0-0 @ 180#	0.22	3.30	8.20	-4.90
10-32-10 @ 225#	1.69	25.35	13.50	11.85
21-0-0 @ 140#	1.27	19.05	5.00	14.05

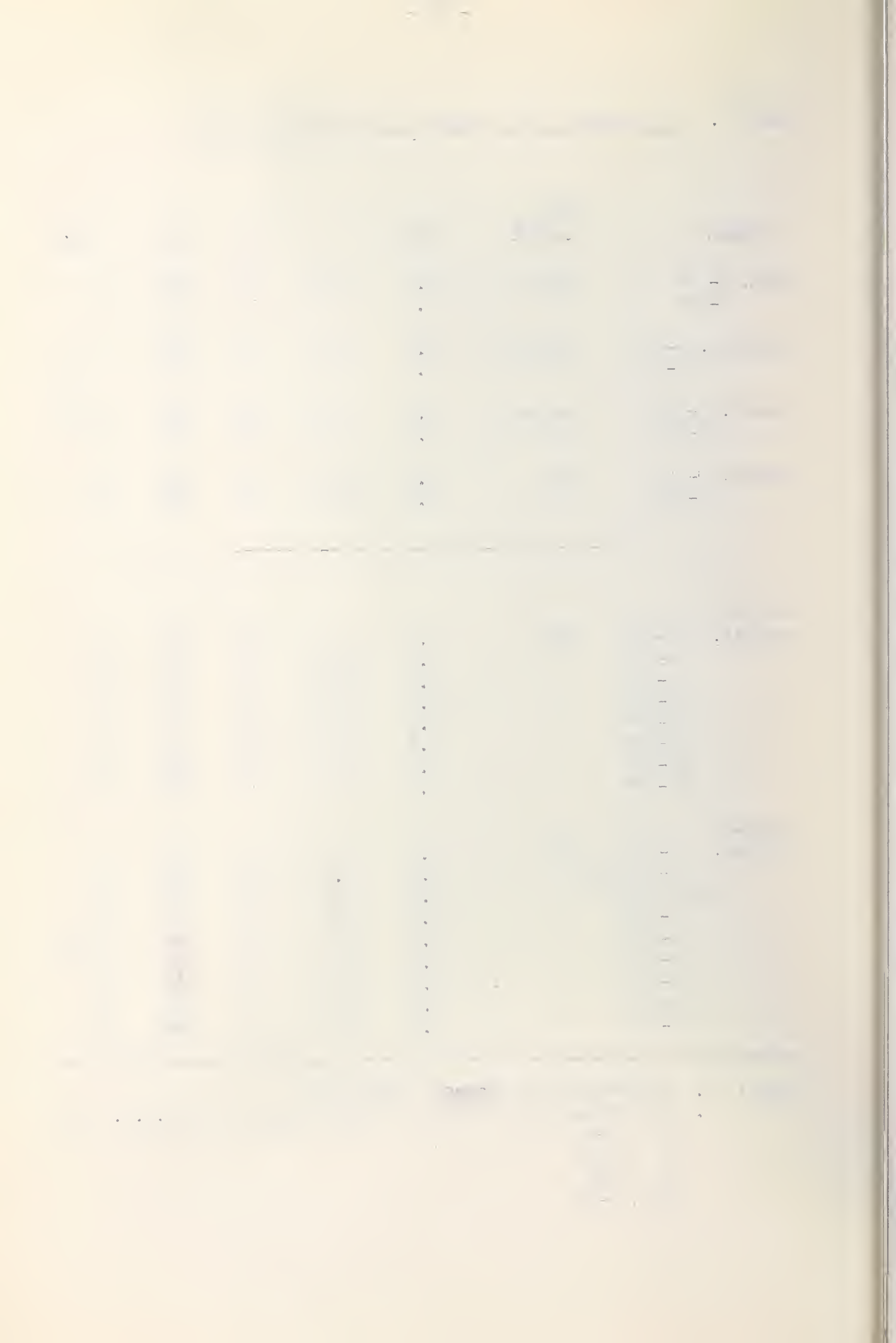
* Conservative figure for feed prices in 1954.

TABLE 3. pH & SPURWAY TEST RESULTS FOR BONNYVILLE SOILS

<u>Sample</u>	<u>Soil zone</u>	<u>pH</u>	<u>P</u>	<u>K</u>	<u>Ca</u>	<u>Mg.</u>
Dery, 0- 6"	Black	6.1	3/4	6	100	3
6-12"	"	6.0	1/4	7	70	3
Turcotte, 0- 6"	Degraded	6.7	3/4	6	125	3
6-12"	"	6.8	1/2	7	70	3 1/2
Dumont, 0- 6"	Degraded	6.9	1/4	20	100	2 1/2
6-12"	"	6.3	1/2	25	70	2
Dumont, 0- 6"	Grey	7.0	1/2	9	150	6
6-12"	"	7.5	1/4	12	125	3

Sylvain						
profile, 1/2- 3"	Grey	6.9	3	15	130	3
3- 9"		6.7	3/4	8	90	1
9-10"		6.2	1/3	8	70	2
10-18"		5.4	1/4	6	70	2
18-20"		5.0	1/3	8	70	2
20-27"		5.2	1/3	10	70	2
27-34"		7.1	1/2	5	125	2
34-48"		7.7	0	8	175	3
Laporte						
profile, 0- 1"	Grey	6.7	1/2	25	175	2
1- 2 1/2"		6.2	3/4	15	125	3
2 1/2- 4"		6.0	1/3	10	75	2
4- 9"		6.0	1/3	9	50	1
9-13"		5.9	1/4	15	50	1 1/2
13-20"		5.6	1/2	9	50	2
20-26"		5.5	1/4	8	40	2
26-36"		5.9	1/3	8	70	0
36-42"		7.5	1/2	8	180	2

- Notes: 1. Nitrates and sulfates tested zero
2. The recommended levels for field soils are in p.p.m. (48)
- P : 1-2
- K : 5-10
- Ca : 100
- Mg : 5-10



The two sets of profile samples, while very similar in appearance, were analyzed with the hope of explaining the failure of the Sylvain trial to produce results similar to those obtained at Laporte's. The analytical data gave very little indication of a fertility difference. One possible explanation for the failure of the Sylvain test to show a visible response to fertilizer treatment is that the alfalfa crop, on which the trial was placed, was badly winter-killed and consequently seriously affected by weed competition. However, it was gratifying to have the farmer report that, a month after the usual hay harvesting time, the field had been cut for hay, and that the fertilizer treatments had approximately doubled the forage yield.

Feed analysis.

Tables 4 to 8 summarize the chemical determinations carried out on the feed samples. The results compare favorably with analyses of feeds made by Morrison (34), Bertrand (7), Kenwood (21), and Hoff (20). Some of their data are presented in Table 9.

The precision of the results for calcium, magnesium, potassium, sodium, and particularly phosphorus and sulfur, which were all determined on duplicate extracts from nitric-perchloric acid digestion, gives very strong evidence of the validity of this method for the wet-ashing of feed samples. The nitrogen check on six samples of bulk feeds, made after the samples had been remixed and reground, has justified the method of sampling pelleted feed. The greatest difference in nitrogen content of the two sets of samples was only approximately 0.1% and in most cases they varied by only 0.01 to 0.03%.

The meta-vanadate method of determining phosphorus proved entirely satisfactory and recovery tests on unknown solutions were

very accurate. The color developed was very stable and readings of percentage transmission, taken 26 days after the preparation of standards, were within 1% of the original readings on those solutions.

The calcium determination by the direct permanganate method, repeated by the versene method by difference, has given excellent checks. By the direct method the calcium content of the feed was slightly higher. However, on 104 samples analyzed by the two methods, the average difference in calcium content was only 0.01%. The t-test of significance did not indicate any difference at the 5% point. On the other hand the correlation coefficient approached unity or +1.0; the calculated value obtained was 0.986 while the coefficient values necessary for significance, with 100 degrees of freedom, at the 5% and 1% points are 0.195 and 0.254 respectively. Both methods involved approximately the same amount of work and apparently gave comparative results. Since the calcium determination by permanganate is a direct method, it seems that it should be preferred for work of this nature. An attempt to determine calcium on the extracts, using flame photometry, was made. It was discontinued when results did not compare with those reported here and when poor results were obtained for recovery of known amounts of calcium added to extracts from plant ashing. As suggested by Mackay and Delong (25), this was probably due to the interference of phosphate.

Sodium content was very low in all samples and particularly in the forages grown on the grey soils. However, it was felt that the results were fairly accurate, since tests of recovery proved excellent on the samples lowest and highest in sodium. Recovery tests were made by adding known amounts of the elements to the solutions being analyzed.

They were excellent also for the potassium, sulfur and magnesium determinations, and, therefore, justified the use of the methods.

Effects of treatments on feed analysis.

The results of chemical analyses on the forage samples indicate a number of changes in the protein and mineral composition brought about through the effects of fertilizer treatments.

On the black Wetaskiwin soil (Table 4), nitrogen fertilizer has increased the nitrogen and potassium content of alfalfa, and the nitrogen content of grasses. It has decreased the crude fiber content of the crop. The application of phosphorus and sulfur has resulted in increased NPKS content of alfalfa but has affected only the P and K content of grasses. Considering the nitrogen content of the samples from this trial, there appears to be some inconsistency between the samples of pure botanical composition and the unsorted mixture in the bulk feeds. This condition may have been brought about by some error in field sampling or by some deterioration during the curing process, which proved extremely difficult because of the wet season. Another possible explanation is the contamination of the bulk samples through the various processes of preparation into pelleted feed. This is strongly suggested by the high phosphorus content of the 33.5-0-0 treatment of the bulk feed.

On the grey wooded soils, at Foley's and Laporte's (Tables 5 and 6), the ammonium sulfate treatment has increased the nitrogen content of alfalfa, sweet clover and brome. Moreover, nitrogen and sulfur together appear to have increased materially the sulfur content of sweet clover and brome. Phosphorus added to N and S has further increased the nitrogen content of alfalfa, while the complete NPKS fertilizer

TABLE 4. COMPOSITION OF FORAGE FROM BALLHORN'S FARM

Crop	Treatment*	%N	%P	%K	%S	%Ca	%Mg	%Na	% crude fiber
Alfalfa	Check	2.61	0.15	1.68	0.25	2.03	0.51	0.040	
	33.5-0-0	2.79	0.16	2.10	0.28	1.98	0.47	0.030	
	16-20-0	3.05	0.20	2.15	0.37	2.06	0.53	0.042	
	10-32-10	3.33	0.21	2.06	0.33	2.14	0.53	0.030	
Brome	Check	1.35	0.13	1.72	0.13	0.21	0.13	0.004	
	33.5-0-0	1.67	0.11	1.83	0.14	0.23	0.10	0.004	
	16-20-0	1.50	0.21	1.74	0.15	0.28	0.14	0.004	
	10-32-10	1.22	0.19	1.98	0.12	0.21	0.12	0.004	
Timothy	Check	1.23	0.13	1.68	0.11	0.23	0.09	0.004	
	33.5-0-0	1.50	0.11	1.72	0.11	0.25	0.10	0.004	
	16-20-0	1.17	0.20	1.95	0.11	0.27	0.12	0.004	
	10-32-10	1.13	0.19	1.99	0.10	0.20	0.10	0.004	
Bulk	Check	2.06	0.15	1.91	0.20	1.00	0.28	0.020	31.9
Mixture	33.5-0-0	2.48	0.39#	1.71	0.21	1.24	0.25	0.010	27.0
	16-20-0	1.85	0.21	1.92	0.18	0.65	0.23	0.033	32.6
	10-32-10	1.91	0.25	1.96	0.18	0.98	0.26	0.047	32.4

* Rates of fertilizer applications were: 33.5-0-0 @ 180 lb./ac.
16-20-0 @ 360 lb./ac.
10-32-10 @ 225 lb./ac.

Possible contamination of sample.

TABLE 5. COMPOSITION OF FORAGE ON GREY SOIL (FOLEY'S BONNYVILLE)

<u>Crop</u>	<u>Treatment*</u>	<u>%N</u>	<u>%P</u>	<u>%K</u>	<u>%S</u>	<u>%Ca</u>	<u>%Mg</u>	<u>%Na</u>
Alfalfa	Check	2.26	0.24	2.03	0.13	1.55	0.30	0.012
	21-0-0	2.62	0.24	2.03	0.14	1.65	0.35	0.010
	16-20-0	3.02	0.24	2.07	0.24	1.81	0.29	0.015
	10-32-10	3.17	0.26	2.10	0.22	2.00	0.33	0.012
Brome	Check	1.05	0.26	1.73	0.08	0.27	0.10	0.009
	21-0-0	1.68	0.25	1.99	0.15	0.40	0.14	0.006
	16-20-0	1.33	0.22	1.96	0.17	0.29	0.09	0.010
	10-32-10	1.27	0.23	2.45	0.13	0.31	0.11	0.005
Bulk feed Mixture	Check	2.01	0.26	2.43	0.13	1.02	0.24	0.028
	21-0-0	2.04	0.26	2.37	0.20	0.90	0.21	0.030
	16-20-0	1.83	0.27	2.24	0.17	0.86	0.18	0.020
	10-32-10	1.81	0.27	2.23	0.20	0.87	0.19	0.020

* Rates of fertilizer applications were: 21-0-0 @ 140 lb./ac.
16-20-0 @ 360 lb./ac.
10-32-10 @ 225 lb./ac.

TABLE 6. COMPOSITION OF SWEET CLOVER ON GREY SOIL (LAPORTE'S BONNYVILLE)

<u>Treatment</u>	<u>%N</u>	<u>%P</u>	<u>%K</u>	<u>%S</u>	<u>%Ca</u>	<u>%Mg</u>	<u>%Na</u>
Check	2.26	0.23	1.68	0.10	1.64	0.39	0.004
21-0-0 @ 140 lb.	3.11	0.23	1.85	0.31	1.52	0.35	0.009
16-20-0 @ 360 lb.	3.01	0.22	1.50	0.26	1.03	0.25	0.004
10-32-10 @ 225 lb.	3.30	0.27	2.02	0.21	1.50	0.32	0.011

TABLE 7. COMPOSITION OF ALTASWEDE ON GREY SOIL (ATHABASCA 1952)

<u>Treatment</u>	<u>%N</u>	<u>%P</u>	<u>%K</u>	<u>%S</u>	<u>%Ca</u>	<u>%Mg</u>	<u>%Na</u>	<u>% crude fiber</u>
Check	1.90	0.21	1.74	0.08	1.45	0.28	0.014	29.9
S @ 20 lb.	2.03	0.20	1.68	0.11	1.56	0.34	0.016	
16-20-0 @ 100 lb. + S @ 20 lb.	2.09	0.21	1.81	0.10	1.61	0.33	0.019	
16-20-0 @ 100 lb. + K ₂ SO ₄ @ 40 lb.	2.20	0.21	1.53	0.14	1.63	0.42	0.020	29.9

TABLE 8. COMPOSITION OF ALTASWEDE FROM BRETON GREY SOIL

Forage	Treatment*	%N	%P	%K	%S	%Ca	%Mg	%Na
Hand picked (1952)	Check	2.10	0.27	2.42	0.10	1.65	0.29	0.014
	Composite†	2.89	0.27	2.17	0.17	1.60	0.32	0.020
.								
Leaves (1954)	Check	2.78	0.22	1.44	0.13	2.44	0.28	0.014
	Gypsum	3.58	0.15	1.92	0.20	2.93	0.31	0.015
	0-20-0	3.74	0.23	1.32	0.20	2.97	0.36	0.015
	11-48-0	3.70	0.22	1.51	0.19	2.84	0.32	0.020
Stems (1954)	Check	1.36	0.13	1.96	0.05	1.04	0.16	0.004
	Gypsum	1.66	0.12	1.87	0.09	1.29	0.26	0.000
	0-20-0	2.10	0.23	2.37	0.11	1.18	0.28	0.006
	11-48-0	1.98	0.25	2.32	0.10	1.18	0.24	0.006
Whole plant (1954)	Check	1.86	0.22	1.95	0.08	1.45	0.26	0.020
	Gypsum	2.35	0.15	2.08	0.14	1.63	0.30	0.018
	0-20-0	2.58	0.27	2.33	0.14	1.63	0.35	0.032
	11-48-0	2.19	0.27	2.48	0.10	1.59	0.26	0.029

* Rates of fertilizer applications were: Gypsum @ 500 lb./ac. every 5 years.

0-20-0 @ 110 lb./ac.

11-48-0 @ 50 lb./ac.

† 1952 composite from 3 plots fertilized with: 16-20-0 @ 67 lb. + K₂SO₄ @ 33 lb.

21-0-0 @ 75 lb.

16-20-0 @ 67 lb. + manure @ 22 T. every 5 years.

TABLE 9. COMPOSITION OF FORAGE MATERIALS

<u>% element or substance</u>	<u>Alfalfa</u>	<u>Brome</u>	<u>Timothy</u>	<u>Red Clover</u>	<u>Aver. mixed clovers*</u>	<u>Mixtures</u>
N	1.94-3.04	1.58-2.32	0.98-1.55	1.82-2.93	2.28	
P	0.17-0.33	0.28	0.15-0.20	0.19-0.28	0.29	
K	2.01-2.05	2.35	1.41-1.50	1.43-2.26		
S	0.27-0.57	0.09	0.12-0.14	0.14-0.17		
Ca	1.47-2.22	0.20	0.14-0.23	1.35-1.69	1.42	
Mg	0.23-0.40	0.18	0.06-0.12	0.33-0.45	0.32	
Na						0.0013-3.51#
Fibre						22-34

* Average content of mixed clovers at Breton by Kenwood (21)

Figures given by Bertrand and Perieztzeanu (7)

All other figures given by Morrison (34)

has still further increased the nitrogen content of the legumes, the phosphorus content of sweet clover, the calcium and potassium content of all species. Again in the Foley feeds, there is considerable discrepancy in the nitrogen content of the pure botanical samples and the unsorted feed samples. These bulk feeds had to be picked up before they even had an opportunity to wilt; they were still wet when loaded on the truck and transported 200 miles on a hot day. It is therefore strongly suspected that the high yielding treatments of NPS and NPKS have suffered deterioration and loss of nitrogen before they were cured.

At Breton and Athabasca (Tables 7 and 8), the altaswede samples analyzed show that sulfur treatments have resulted in higher percentages of nitrogen, sulfur, calcium and magnesium. Phosphorus applied in combination with nitrogen and sulfur, (or with nitrogen alone at Breton) has further increased the nitrogen content of clover at both locations; it has increased the potassium content of the forage at Athabasca in 1952, and the phosphorus content at Breton in 1954. The addition of potassium to NPS at Athabasca did not materially alter the mineral composition of the crop.

These results are in agreement with data from other workers. Hoff (20) reported increases of sulfur and nitrogen content of forages through the application of sulfur fertilizer in the sulfur-deficient grey wooded soils. Kenwood (21) has found that the treatments giving high yield increases of mixed clovers at Breton have also increased the nitrogen content of the crop. Prince (41) reported increased NPK content of clover through increasing numbers of nitrogen topdressing on annual ryegrass and crimson clovers. Stewart and Holmes (49) found that

nitrogen increased the crude protein content of grassland herbage.

Rost et al (45) MacGregor and Rost (27), Alway and Nesom (3) found that phosphorus fertilization increased the protein content of alfalfa.

Feeding trials.

Tables 10 to 13 give a summary of four bioassay experiments. Since these tables only present the final weight gains of the experimental animals, graphic representation of rabbit growth for experiments 1, 3 and 4 is given in Figure 1.

TABLE 10. EXPERIMENT 1. FEEDING TRIAL WITH ATHABASCA FEED

<u>Treatment</u>	<u>Yield tons/ac.</u>	<u>Replicates</u>	<u>Total gain in grams</u>	<u>Aver. gain</u>	<u>Gr. feed per gram gain</u>
Check	1.1	E3	210	200	12.2
		E4	185		
		B3	175		
		C4	230		
S @ 20#	2.4	E1	365	345*	8.4t
		E11	420		
		B10	375		
		C3	220		
16-20-0 + S	2.8	E5	425	432*	8.4t
		E9	490		
		B8	(died)		
		C2	350		
16-20-0 + potassium sulfate	1.7	E2	440	485*	6.1
		E10	585		
		B7	505		
		D2	405		
M.S.D. to compare aver. gain				75	

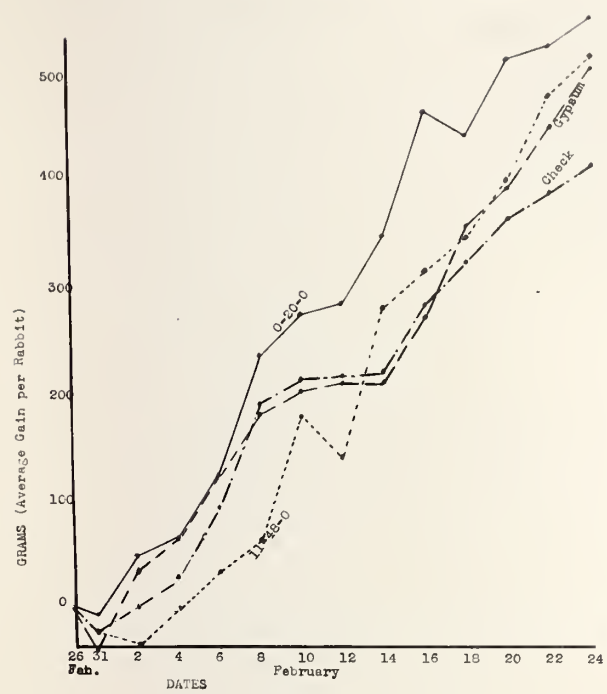
* Statistically significant compared to check.

t Records of feed consumption were not accurate, only estimates.

Note: Length of feeding trial was 21 days.

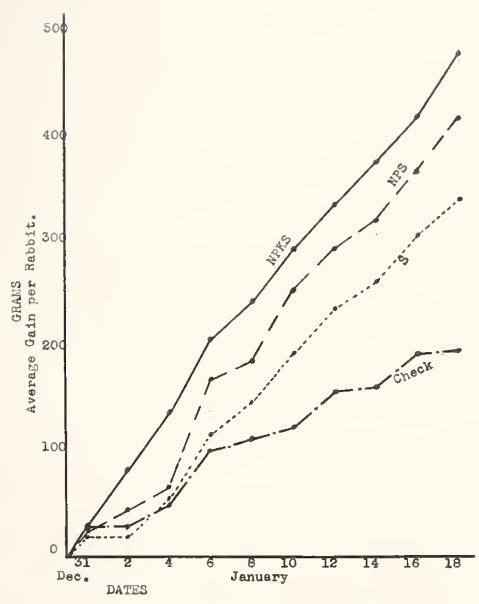
FIGURE 1.

GROWTH CURVE OF RABBITS
on
BRETON FEED 1954



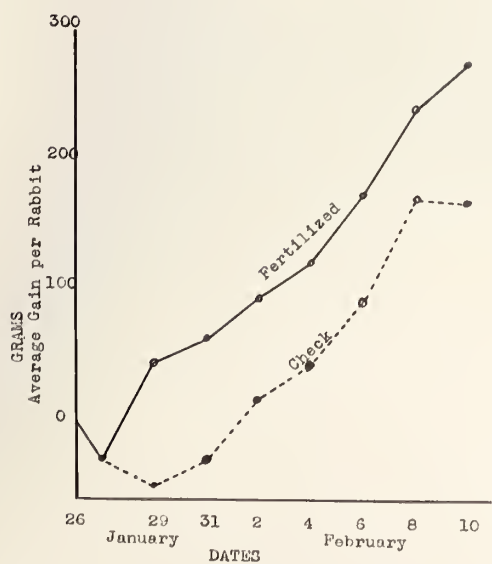
Exp. 3

GROWTH CURVE OF RABBITS
on
ATHABASCA FEEDS



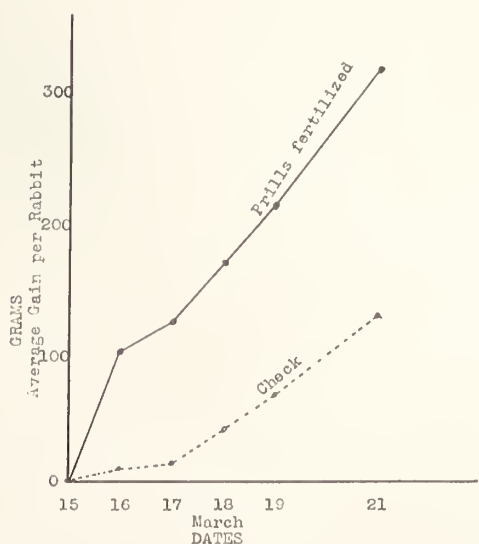
Exp. 1

GROWTH CURVE OF RABBITS
on
BRETON FEEDS 1952



Exp. 2

GROWTH CURVE OF RABBITS
on
BALLHORN FEED



Exp. 5

An analysis of variance carried out on the results obtained in Experiment 1 showed highly significant differences in the total weight gains of the rabbits. Sulfur alone applied as a fertilizer to the altaswede crop has produced forage superior in feeding value to the same hay grown without fertilizer at Athabasca. When sulfur was combined with ammonium phosphate, 16-20-0, the feed value obtained, as shown by the rate of gain of the experimental animals, was still further increased significantly. Due to considerable spilling on these two feeds, it was difficult to measure any great increase in feed efficiency. However, with the NPKS treated forage, not only was the rate of gains of the rabbits more than twice as great as those of the check group, but the efficiency of the feed, measured by the ratio of feed consumption to weight gains, was increased by exactly 100%.

The results of the palatability trial were striking for the Athabasca feeds. The consumption for the NPKS fertilized material was 1,720 grams compared with 1,065 grams of the check feed. The other two treatments were almost completely rejected, only 210 and 220 grams being consumed.

The salt consumption, during the feeding trial, may be worth mentioning. Two rabbits in the same cage, fed on the check feed, consumed practically their entire salt block, while the other rabbits ate a negligible portion.

The four rabbits on the check feed showed signs of paleness and malnutrition towards the end of the experiment. In one cage two rabbits were developing cannibalistic tendencies and had to be separated. A test for hemoglobin failed to show that the rabbits in the check group

suffered from anemia, even though their average hemoglobin count was considerably lower than that of other groups. A statistical analysis of the hemoglobin counts did not reveal a significant difference between the groups, although the value obtained came very close to the 5% point.

TABLE 11. EXPERIMENT 2. FEEDING TRIAL WITH FOLEY FEED

<u>Treatment</u>	<u>Replicate</u>	<u>Total gain in grams</u>	<u>Aver. gain per rabbit, grams</u>	<u>Grams feed per gram gain</u>
Check	A2	405	391	10.2
	D5	350		
	A5	485		
	D8	325		
(NH ₄) ₂ SO ₄	E6	255	291	16.6*
	D7	315		
	A6	355		
	D4	240		
16-20-0	A1	185	280	10.8*
	D6	120		
	A4	415		
	D1	400		
10-32-10	B6	165	310	12.2*
	D3	355		
	A3	475		
	D9	245		

* Records of feed consumption are only estimates.

No significant difference between treatments.

The feeding trial lasted 21 days.

The sixteen rabbits used in this experiment were very variable and it was difficult to allot them in representative groups for the four treatments. As the analysis of variance showed, the differences in weight gains due to replicates were greater than those due to treatments. No significant difference was obtained between the rates of gain or feed efficiencies of the four groups. However, the palatability trial showed a distinct advantage of the complete NPKS fertilized feed

over the ammonium sulfate feed. The consumption of the forage taken from the 10-32-10 was 1,610 grams, compared with 270 grams for the 21-0-0 treated forage.

TABLE 12. EXPERIMENT 3. FEEDING TRIAL WITH BRETON FEED 1954.

<u>Treatment</u>	<u>Replicate</u>	<u>Total gain in grams</u>	<u>Aver. gain per rabbit, grams</u>	<u>Grams feed per gram gain</u>
Check	G3	215		
	H4	575		
	I3	390	397	10.8
11-48-0	G1	500		
	H3	560		
	I2	510	523	12.2*
Gypsum	G4	495		
	H1	460		
	I1	555	503	13.7*
0-20-0	G2	500		
	H2	655		
	I4	575	577	8.6

* Records of feed consumption are only estimates.

Length of feeding trial 31 days.

No significant difference between treatments.

Losses of rabbits through a severe case of coccidiosis, which wiped out a whole litter, reduced the number of experimental animals to three per group in Experiment 3. This reduction in the number of replicates made it difficult to measure accurately the improvement in feed value by statistical methods. Although the analysis of variance failed to determine any significant difference in weight gains due to treatments, on the average the rabbits fed fertilized feeds from the 1954 Breton Plots did much better than those on the unfertilized forage.

TABLE 13. EXPERIMENT 4. FEEDING TRIAL WITH BRETON FEED 1952

<u>Treatment</u>	<u>Replicate</u>	<u>Total gain in grams</u>	<u>Aver. gain per rabbit, grams</u>	<u>Grams feed per gram gain</u>
Check	J5	250		
	J10	185		
	J7	130		
	J9	125	172	16.2
Composite*	J3	315		
	J4	240		
	J6	290		
	J8	185	257*	11.2
M.S.D. to compare average gain.			49	

* Composite feed from three high yielding fertilizer treatments.

* Statistically significant compared to check.

Length of feeding trial 15 days.

Experiment 4 with the 1952 Breton feeds showed significant differences in rates of animal gain and feed efficiency.

Data from experiments 3 and 4 clearly indicate that, on the Breton grey soils, commercial fertilizer containing sulfur or phosphorus, or both these elements, may be expected to increase the feed value of altaswede clover by 25 to 50%. These results agree very well with those obtained by Renner and Bentley in 1951. (See appendix.) It is of interest to note that the ratio of weight gains of the animals on the Breton feeds followed very closely the ratio of the nitrogen and phosphorus content of these forages. (Table 8.)

A fifth feeding trial was started with the Ballhorn feed, using forage from the check strip and forage from the ammonium nitrate treatment. The trial was not completed at the time of this

report, but the general trend of results, six days after the start of the experiment, is indicated by the growth curves in Figure 1. The great difference in weight gains of the animals on the fertilized feed is certainly due in part to the lower crude fiber content of the forage, as well as to the increase in protein content. As with the Athabasca feed trial, it would be difficult to explain fully the magnitude of weight gain differences from the chemical composition of the forages alone. There is a possibility of a greater vitamin content of the fertilized forage. An insufficiency of thiamine, for example, may have been responsible for the poor growth of the animals on the check feed. Another possible explanation is the difference in the percentage of some essential amino acid such as methionine, which in the case of the Athabasca feed is strongly suggested by an increase of sulfur content from 0.08% in the check to 0.14% in the complete NPKS fertilized forage. Renner et al. (43) have shown that sulfur containing fertilizers have increased the proportion of some essential amino acids when grain was grown in rotation with legumes. Similar effects may be obtained from the fertilization of forage. In that case, the better growth of the rabbits in these experiments may be due to an improved quality as well as quantity of protein.

The palatability trial with the Ballhorn feeds was most striking. The rabbits definitely preferred the ammonium nitrate fertilized feed, consuming 3,040 grams of this forage compared to 840 grams of the 16-20-0 treatment, 660 grams of the 10-32-10, and only 410 grams of the check feed. During the course of this palatability trial, the bowls containing the various feeds were

changed around, but the animals were in no way confused by this substitution. They consistently fed on the ammonium nitrate fertilized forage in preference to the others. What constituent in the feed made it more relished by the rabbits? Could the carbohydrate content of the feed make the difference? In trying to explain the preference of cattle for forage growing on old manure spots, Sykes (50) refers to the term "sweeter" grass, and to the effects of available phosphates in the production of a highly palatable forage.

DISCUSSION OF RESULTS

The validity of using rabbits as pilot animals to determine the nutritive value of forages may be questioned. However, there is evidence to show that the rabbit is a very valuable animal for feeding trials of this nature. Bernier (6) states that the digestive system of the rabbit is similar to that of a horse. It has a well developed cecum adapted to the assimilation of cellulose. Crampton et al.(10), in comparing the relative ability of steers and rabbits to digest pasture herbage, found that the rabbit will digest dry matter 71 to 85% as efficiently as the steer. They also found a high correlation between their relative abilities to digest crude protein and lignin. Matrone et al.(29) suggested that the rabbit may be a better experimental animal than sheep for investigations seeking to find fertilizer induced differences in nutritive value of forages. The reason given was that the rabbit's digestive system is not as independent of B vitamins as the ruminant's.

The investigation has given evident proof that, in order to fully evaluate the effects of commercial fertilization of forages in Alberta, the worker can not restrict himself to field trials and yield tests. Highly profitable yield increases may be obtained as a result of a fertilizer treatment, but in many cases, the increment in total digestible nutrients and health producing elements in the fertilized forage may be more valuable than the visible increased tonnage. Results of the feeding trials carried out in this project clearly indicate that the chemical analysis of feed samples does not give an accurate measure of their value in producing growth of animals. There is no doubt that feeds higher in nitrogen, phosphorus and calcium content are desirable, but these could be given as supplements. "The animal, unlike the plant, cannot subsist

on simple elemental substances and needs numerous complex substances that in many cases are ill-defined or not defined at all chemically. Moreover, the effects of nutrient interactions on the physiological processes of the animal are generally unknown. Further, just as the content of a mineral element in the soil is not a measure of its availability, similarly, the content of a nutrient in the plant is not a measure of its availability to the animal." (29).

Thus the Foley feeds (Experiment 2) did not produce any different weight gains in the rabbits, although they differed markedly in their chemical composition. The Athabasca feeds (Experiment 1), while not differing any more than the Foley feeds in their mineral contents, have given spectacular differences in animal growth and feed efficiency. Finally, the rabbits on the Breton feeds (Experiments 3 and 4) showed a performance closely correlated to the protein and mineral content of the forage.

Bioassays carried out elsewhere corroborate these data. Matrone et al. (29) (30), McLean et al. (32), Smith and Albrecht (46) have conducted feeding trials in the United States and have all concluded that the animal response to fertilized feed could not be entirely explained by the chemical analysis of the plant materials. "Such factors as the effect on animal health, relative bulkiness, effects of changing composition (both physical and chemical) on forage intake, digestibility, and ration balance," states McCullough, "apparently determine the usefulness of the forage dry matter produced." Albrecht's (2) report of cattle preference for haystacks from a field eight years after its fertilization is definite evidence that animals will determine

the difference in quality of feed when chemical analysis will fail to indicate any variation.

To the farmers of Alberta the results of this project have an extremely important practical significance. They show beyond any doubt that the calculation of yield increases alone are not a satisfactory measure of the effects of commercial fertilizers applied to forage crops in the province. A substantial value must be given to the increase in nutritive quality of the forage, as indicated by increased content of protein and essential mineral elements, higher palatability and greater efficiency of the feed itself. This value, which too often goes unnoticed, may be the most important from the standpoint of monetary returns from fertilizer use. The cost of handling good and poor feed is about the same; but feeding more forage to animals to produce the same results will involve greater expense of time and effort. What about the general health of livestock? What about the savings of expensive protein and mineral supplements? What about the elimination of veterinary bills, losses of animals and reduction in production? The livestock man knows that the time, labor and animal lives saved by using good quality feed are often more important than the availability of cheap feed. The farmers and the feeders in some areas of Alberta can obtain feed of greater value at a lower cost by using suitable commercial fertilizers. By following this practice, not only will they be increasing their income, but they will be taking a very important step towards basic soil conservation, which is the key to sound farming and a prosperous permanent agricultural economy.

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APPENDIX

The results of four feeding experiments are summarized in tables 14 to 17. The trials, using rabbits as test animals, were conducted in 1951, at the University of Alberta, in an endeavour to determine whether or not the feeding values of the hays had been affected by various types of fertilization. For giving him permission to use this data, the author is greatly indebted to Ruth Renner and Dr. C. F. Bentley who carried out the actual feeding trials.

TABLE 14.

EXPERIMENT 1 GROWTH OF RABBITS FED ALTASWEDE CLOVER FROM BRETON FIELD, 1950

<u>Feed from treatment</u>	<u>No. of days on experiment</u>	<u>Aver. daily gain, grams</u>
Check	16	12.3
Complete	"	21.8*
21-0-0	"	22.0*
Lime + triple	"	15.1
Manure + 16-20-0	"	16.6

M.S.D. 6 grams

* Statistically significant compared to check.

TABLE 15.

EXPERIMENT 2 GROWTH OF RABBITS FED ALFALFA FROM BRETON FIELD, 1950

<u>Feed from treatment</u>	<u>No. of days on experiment</u>	<u>Aver. daily gain, grams</u>
Check	18	11.4
Complete	"	15.7*
21-0-0	"	12.9
Lime + triple	"	19.1*
Manure + 16-20-0	"	20.3*

M.S.D. 4 grams

* Statistically significant compared to check.

TABLE 16.

EXPERIMENT 3 GROWTH OF RABBITS FED COMPOSITE HAY FROM SOUTHERN ALBERTA

<u>Feed from treatment</u>	<u>No. of days on experiment</u>	<u>Aver. daily gain, grams</u>
Check	15	25.0
33.5-0-0	"	28.0
16-20-0	"	29.3
21-0-0	"	26.6
11-48-0	"	41.2

No statistical significance to these differences.

TABLE 17.

EXPERIMENT 4 GROWTH OF RABBITS FED ALFALFA FROM NEAR VILNA

<u>Feed from treatment</u>	<u>No. of days on experiment</u>	<u>Aver. daily gain, grams</u>
Check	21	12.5
21-0-0	"	15.7
Gypsum	"	14.6
16-20-0	"	14.0
Sulfur	"	15.9
Trace Elements	"	14.8

No statistical significance to these differences.

Tables 18 and 19 present a brief summary of the results of the fertilizer trials carried out on forage crops at Breton. The tests at Breton have been conducted continuously since 1930 and the data presented in these tables summarize accurate long-term results for legume hay on a sulfur-deficient grey soil. Since the grey soil of Breton may be more sulfur-deficient than other grey wooded soils in the province, one may expect somewhat less spectacular increases of forage yields from the sulfur-bearing fertilizers in other areas.

Tables 20 to 25 are compilations of co-operative fertilizer tests carried out on Alberta forage crops during the last six years. All the data presented can be obtained from the yearly reports of the Alberta Advisory Fertilizer Committee, 1949-1954. They are grouped here and averaged for the different soil zones.

Table 26 gives a summary of the individual plant nutrients, nitrogen, phosphorus, potassium and sulfur, supplied to the soil by the various rates of application of the commercial fertilizers used in the co-operative trials.

TABLE 18.

EFFECTS OF FERTILIZERS ON YIELDS OF LEGUME HAY BRETON PLOTS, 1930-1953 (17)

<u>Treatment</u>	Average hay yield per acre for 5-year rotation of wheat-oats-barley-hay-hay			
	<u>Year 4</u> <u>Yield</u>	<u>(Tons/acre)</u> <u>Increase</u>	<u>Year 5</u> <u>Yield</u>	<u>(Tons/acre)</u> <u>Increase</u>
Check (no fertilizer)	0.5	---	0.3	---
Manure*	1.3	0.8	1.2	0.9
16-20-0 + K ₂ SO ₄ @ 75 lb.	2.5	2.0	2.3	2.0
Ammonium sulfate @ 75 lb.	2.2	1.7	2.1	1.8
Manure + 16-20-0 @ 75 lb.	2.3	1.8	2.1	1.8
16-20-0 @ 75 lb.	2.3	1.8	2.2	1.9

* Manure at 20 tons per acre once in 5 years.

TABLE 19.

CLOVER YIELDS BRETON PLOTS FOR THE 7-YEAR PERIOD 1940-1946 (36)

<u>Treatment</u>	<u>Clover & alfalfa</u> <u>(Rotation)</u>		<u>Alfalfa continuous</u>	
	<u>Yield</u> <u>ton/ac.</u>	<u>Increase</u> <u>ton/ac.</u>	<u>Yield</u> <u>ton/ac.</u>	<u>Increase</u> <u>ton/ac.</u>
Check (no fertilizer)	0.6	---	0.5	---
11-48-0	1.3	0.7	1.1	0.6
2-20-0	3.0	2.4	2.4	1.8
0-20-0	2.8	2.2	2.2	1.4
Bonemeal	0.9	0.3	1.4	0.5
Check	0.7	---	1.0	---
33.5-0-0	0.8	---	1.1	---
33.5-0-0 + Gypsum	2.6	1.7	2.7	1.7
Gypsum	2.6	1.5	2.7	1.6
Check	1.3	---	1.1	---
Na ₂ SO ₄	2.7	1.3	2.5	1.4
K ₂ SO ₄	2.6	1.3	2.7	1.7
K ₂ SO ₄ + Na ₂ SO ₄	2.5	1.3	2.7	1.6
Check	1.3	---	1.1	---

Note: Increases calculated using sliding scale from check.

TABLE 20. RESULTS OF CO-OPERATIVE FERTILIZER TRIALS ON FORAGE CROPS IN THE DARK BROWN SOIL ZONE*

Farmer's name	Year	Yield of Check	Yield increases of fertilizer treatments over check, tons/acre.												
			33.5-0-0 @ lb./ac.		11-48-0 @ lb./ac.		16-20-0 @ lb. /ac.		21-0-0 @ lb./ac.		Crop				
			50	90	135	180	35	100	85	180			250	80	145
Cavanaugh	1950	0.8	0.2		0.3		0.2	0.2	0.3		0.4	0.2		0.2	Brome
McKinnon	"	0.3	0.3		0.3		0.1	0.1	0.1		0.3	0.1		0.3	"
Rudolph	"	0.7	0.4		0.9		0.2	0.3	0.3		0.8	0.4		0.7	"
Usher	"	0.6	0.4		0.6		0.1	0.3	0.3		0.5	0.3		0.6	Alf. Br.
Garrett	1952	1.2				1.7				1.0					Brome
Dekker	1953	0.6	0.4	0.3		0.4				1.3					Brome
Milnes	"	0.6	0.6	0.9		1.7				1.5			0.9		"
Bach	1954	0.7		0.1		0.5				0.3					Cr. Wh.
Milnes	"	1.4		0.9		1.5				1.6			0.4		Brome
Anchor Bar	"	1.0				1.1				1.4			0.6		"
Average		0.8	0.4	0.5	0.5	1.1	0.1	0.2	0.2	1.2	0.5	0.2	0.6	0.6	

* Summarized from A.A.F.C. reports, 1950-1954.

Note: All trials were on field strips.

TABLE 21. RESULTS OF CO-OPERATIVE FERTILIZER TRIALS ON FORAGE CROPS IN THE THIN BLACK SOIL ZONE*

Farmer's name	Year	Yield of check, tons/ac.	Yield increases of fert. treat. over check, tons/ac.					Crop		
			33.5-0-0 @ lb./ac.	11-48-0 @ lb./ac.	16-20-0 @ lb./ac.	21-0-0 @ lb./ac.				
			50 <u>135</u> 180	75 <u>150</u> 225	85 <u>180</u> 265	80 <u>145</u> 225	195			
Hart	1952	0.7	0.3	0.5	0.1	0.3	0.2	0.7	Leg. Gr.	
Peterson	1953	0.9			1.2	1.4	1.5	1.4	Br. Alf.	
Clark	1954	1.9			0	0.1	0.4	0.4	Brome	
Verm. Sch.	"	0.4			0	0	-0.1	0.3	"	
Warren	"	0.9		0.1	0.8	1.0	1.2	1.7	Br. Alf.	
Average		1.0	0.3	0.5	0.1	0.4	0.5	0.2	0.7	

* Summarized from A.A.F.C. reports, 1952-1954.

Note: All trials were on field strips.

TABLE 22. (continued)

Farmer's name	Yield of check, tons/ac.	Yield increases of fertilizer treatments over check, tons/ac.										Crop				
		33.5-0-0 @ lb. /ac.		11-48-0 @ lb./ac.		16-20-0 @ lb./ac.		21-0-0 @ lb. /ac.		10-32-10 @ lb./ac.						
		50	135	180	35	75	100	150	85	180	250		360	80	145	195
Campbell	0.7					0.3		0	0.3	0.5				0.3		Br. Alf.
Herveny	0.4			0.8		0.4		0.5	1.6	2.4						" "
Hueldenhaar	1.3			0.1		1.2		1.4	1.7	1.6						" "
Animal Sc.	1.2					0.1		0.2	0.3	0.5						Br. Tim.
" 2nd cut	1.1					0.5		0.5	0.3	0.6						" "
Hirsekon	2.0			0		0		0	0	0						Alfalfa
Ballhorn	0.8			1.0		0.9		0.9	1.8	2.3			0.2		0.4	Leg. Gr.
Thompson	0.9	0.1	0.7		0.7		0.9									" "
Ballhorn	0.8			0.4		0.2		0.6	0.6	1.1				0.3		Br. T. Alf.
Morris	1.7			0.2		0.7		0.6	0.6	1.0				0.5		Br. Alf.
Berry#	2.3			0.7		1.5		2.3	1.9	2.4				1.0		" "
Loupe	0.8			0.2				0.5	0.5	0.8				0.4		Br. T. Alf.
Wlds Sch.	1.7			0.5		0.2		0.3	0.3	0.4				0.4		Br. R. Cl.
Paul	1.9			0.2		0.1		0.3	0.2	0.4				0.4		Br. Tim.
Stuart	0.6			0.2				0.5	0.2	0.3				0.2		Brome
Dopper	0.5			0.7					0.7	0.9						Br. R. Cl.
Schalin	(Not sampled)															
Average	0.8	0.2	0.3	0.4	0.3	0.5	0.3	0.6	0.2	0.8	0.4	0.9	0.2	0.5	0.3	0.9

Yield reported as total of two cuttings.
 * Summarized from A.F.C. reports, 1949-1954.
 Note: All trials reported were on field strips.

TABLE 23 RESULTS OF CO-OPERATIVE FERTILIZER TRIALS ON FORAGE CROPS IN THE DEGRADED BLACK SOIL ZONE*

Farmer's name	Yield of check, tons/ac.	Yield increases by fert. treat. over check in tons per acre.							Crop
		33.5-0-0 @	11-48-0	16-20-0 @	21-0-0 @	10-32-10			
		lb./ac.	lb./ac.	lb./ac.	lb./ac.	@ lb./ac.			
	50	90	75	85	100	145	195	225	
		180	150	180	360				
Plante#	0.4			0.1		0.1			Altasw.
Dumont#	0.5								Alfalfa
Adair	0.7	0.2	0	0.1	0	0.1			Alsike
Boje	nil		0.1	0.1			0.1		Alfalfa
Fielhaber	0.7		0.1	0.3	2.3	1.9	1.4		Br. Alf.
Zeigler	0.4	1.0			1.2		1.1	0.9	Timothy
Turcotte&	2.6	0.5	0.7	1.3	1.9	2.6	1.9	2.9	Br. Alf. Fes.
Average	0.8	0.2	1.0	0.8	0.3	0.1	1.5	0.1	1.8

* Summarized from A.A.F.C. reports, 1949-1954.
 # Trials at Plante's and Dumont's were on plots instead of field strips.
 & Yields reported as totals of two cuttings, for Turcotte's trial.

TABLE 24. RESULTS OF CO-OPERATIVE FERTILIZER TRIALS ON FORAGE IN GREY SOILS NOT SULFUR-DEFICIENT*

Farmer's name	Yield of check, tons/ac.	Yield increases by fert. treat. over check in tons per acre.										S @	Crop
		11-48-0		16-20-0 @		21-0-0 @		Na ₂ SO ₄ @		CaSO ₄ @		Trace+S	
		lb./ac.		lb./ac.		lb./ac.		lb./ac.		lb./ac.		@ lb./ac.	
		75	180	360	80	145	80	110	20	20	20	lb./ac.	
Agnew	1.7												Past.Mix.
Roberts	0.7												" "
Montonati	nil												Alfalfa
Branscombe	1.1		0.8		0.3								"
Hoff	1.6		0.3		0.1		0	0.2	0.1	0.4			"
Laukkanen	2.2		0.5		0.8		0	0.1	-0.1	0			"
Hoff	3.9	0.5	-0.1	-0.1		-0.2	0.2	0.3	0.2	0.3			"
Average	1.6	0.5	0.4	-0.1	0.4	-0.2	0.1	0.2	0.1	0.2	0.1	0.2	

* Summarized from A.A.F.C. reports 1949-1953.

Notes: The first three trials were too light to sample.

The Branscombe, Hoff and Laukkanen, in 1952, were plots instead of strips.

TABLE 25. RESULTS OF CO-OPERATIVE FERTILIZER TRIALS ON FORAGE IN SULFUR-DEFICIENT GREY SOILS*

Farmer's name	Yield of check, tons/ac.	33-0-0 @ lb./ac. 180	11-48-0 @ lb./ac. 75	16-20-0 @ lb./ac. 100 180 360	21-0-0 @ lb./ac. 80 145	10-32-10 @ lb./ac. 225	Na ₂ SO ₄	CaSO ₄	Trace + S	Sulfur	
Bessaraba#	0.1			0.3	0.3		0.2				Alfalfa
Dumont#	0.1			0.2	0.1		0.2				"
Winter	0.5	(No significant increase reported)						110	20	20	Crop
Alexander#	0.3			1.4			0.2				Past. M.
Partridge#	0.7			1.0	1.0		0.9	1.0		0.6	Alfalfa
Edwards#	1.4			2.5	1.4		1.4	1.6	1.6	0.5	Alsike
Gogowich#	1.5			0.6	0.6		0.4	0.4	0.4	0.1	Alfalfa
Howiuk#	1.5			1.5	1.3		1.0	1.4	1.4	0.1	"
Mikkelsen#	2.3			1.4	1.4		1.2	1.2	0.9	0.2	"
Farrell#	1.0			1.3	1.2		1.4	1.4	1.2	0.3	"
Snowden#	1.1			0.1	-0.1		0.1	0	-0.1	-0.2	"
Dumont	1.9	-0.4	0.6	1.3	1.5	1.5					"
Foley	1.5	0.4	0.5	1.2	1.8	1.5					Br. Alf.
Laporte	0.6	0.1	0.7	1.1	1.1	1.5					Sw. Cl.
Verrier	1.5	0.2	1.0	1.8	2.1	1.5					Alfalfa
Sylvain	(Not sampled)										"
Average	1.0	0.1	0.7	1.0	0.8	1.5	0.7	1.0	0.9	0.2	

* Summarized from A.A.F.C. reports, 1949-1954.
Plots instead of field strips.

TABLE 26. APPROXIMATE NUTRIENT IN TREATMENTS USED IN CO-OPERATIVE TRIALS

<u>Fertilizer</u>	<u>Analysis</u>	<u>Applic. lb./ac.</u>	<u>Nutrients supplied, lb./ac.</u>			
			<u>N</u>	<u>P₂O₅</u>	<u>K₂O</u>	<u>S</u>
Ammonium nitrate	33.5-0-0	35	15			
		90	30			
		135	45			
		180	60			
Ammonium phosphate	11-48-0	35	3	15		
		75	8	35		
		100	11	50		
		125	13	60		
		150	15	70		
Ammonium phosphate	16-20-0	85	12	15		10
		100	16	20		14
		150	24	30		20
		180	28	35		24
		200	32	40		27
		250	40	50		34
		360	56	70		47
Ammonium sulfate	21-0-0	80	15			20
		100	20			25
		145	27			35
		195	40			50
Complete	10-32-10	225	20	70	20	18
Sodium sulfate	Na ₂ SO ₄	80				20
Gypsum	CaSO ₄	110				20
Trace elements + sulfur						20
Sulfur		20				20

COLORIMETRIC PHOSPHORUS DETERMINATION

BY META-VANADATE METHOD

1. Reagents: (a) 0.25% Meta-vanadate, NH_4VO_3
(b) 5% Ammonium Molybdate
(c) 1:2 HNO_3 (1 part HNO_3 , 2 parts H_2O)
(d) Standard 50 p.p.m. phosphorus solution prepared
by dissolving 0.2195 g. KH_2PO_4 in 1 litre H_2O .
2. Standard curve: Prepare eleven standard solutions of 0 to 10
p.p.m. To 50 ml. volumetric flasks add aliquots of
the standard 50 p.p.m. phosphorus solution and water
to give approximately 30 ml. total. To each flask
add in the following order:
(a) 5 ml. of 1:2 HNO_3 (from burette or volumettor),
(b) 5 ml. of 0.25% Meta-vanadate,
(c) 5 ml. of 5% Ammonium Molybdate,
(d) Distilled water to 50 ml. mark.
Mix well after each addition by swirling.
Using blue filter # 415, adjust blank solution to 100%
transmission and record percent transmission of other
10 solutions containing 1 to 10 p.p.m. Graph curve
of percent transmission against p.p.m.
3. Determining unknowns: Measure aliquot of unknown extract to make
up a 50-ml. solution containing between 1 and 10 p.p.m.
phosphorus. (For hay samples wet ashed by nitric-perchloric
acid, 3 g. feed in 200 ml. extract, use a 5-ml. aliquot.)

Add in the following order, mixing after each addition:

- (a) 5 ml. of 1:2 HNO_3 ,
- (b) 5 ml. of 0.25% Meta-vanadate,
- (c) 5 ml. of 5% Ammonium Molybdate,
- (d) Distilled water to make up 50 ml. of solution.

Determine % transmission with colorimeter, using blue filter # 415.

From standard curve read phosphorus content in p.p.m.

Convert to % phosphorus.

4. Notes:
- (a) Ion interference. The error will not exceed 2% for amounts up to 1,000 p.p.m. of any of the following ions: Al, NH_4 , Ba, Be, Cd, Hg, K, Ag, Na, Sr, Sn, U, Zn, Zr, Ca, Fe, Pb, La, Mg, Mn.
 - (b) Stability. Solutions carrying 5 p.p.m. phosphorus, stored in pyrex, are stable for seven weeks.
 - (c) Concentration. Beer's law applies up to 40 p.p.m.
 - (d) Temperature. Solutions must not be boiled after the addition of vanadate.

PHOTOMETRIC DETERMINATION OF SODIUM

A. Preparation of standard curve.

1. Prepare seven standard solutions of NaCl containing 30, 25, 20, 15, 10, 5, and 0 (blank) p.p.m. sodium from an accurate 50 p.p.m. Na, in the following manner:
 - (a) To 50 ml. volumetric flasks add aliquot of accurate standard. (E.G. 30 ml. for 30 p.p.m., 20 ml. for 20 p.p.m., etc.)
 - (b) To each add 3 ml. of a buffer ion mixture containing
 - 2,000 p.p.m. Ca,
 - 500 p.p.m. Mg,
 - 2,000 p.p.m. K,
 - 500 p.p.m. P.
 - (c) Make up to 50 ml. of solution with distilled water. Mix well. Stopper tightly until used. (N.B. 250 ml. of 10 p.p.m. Na was made up instead of 50, by multiplying ingredients by 5.)
2. Set the Beckman Model DU flame spectrophotometer to obtain a curve varying from approximately 0% to 100% transmission with the above solutions. The following adjustments were adopted:
 - (a) Fuel at 2.5,
 - (b) Oxygen at 13,
 - (c) Wave length at 589.2,
 - (d) Slit width at 0.01,
 - (e) Selector switch at 0.1,
 - (f) Blue phototube,
 - (g) Phototube load resistor at 2,
 - (h) Photomultiplier sensitivity at 4,
 - (i) Zero Suppression at 1.

3. Balancing the machine with the standard 30 p.p.m. Na at 100% transmission, obtain readings for the other six standard solutions. Graph curve of percent transmission against p.p.m.

B. Determining unknowns.

1. Prepare a buffer ion mixture to obtain the same concentration of ions in unknown solutions as was added to standards. For a 1:1 dilution of extract from nitric-perchloric acid digestion of plant materials -- 3 grams to 200 ml. of solution -- the buffer ion mixture was made up of 60 ml. of the original buffer diluted to 500 ml. For a 3:1 dilution (3 parts unknown solution, 1 part buffer) the buffer ion mixture was made up of 120 ml. of the original buffer diluted to 500 ml.
2. Pipette aliquot of unknown into beaker. (e.g. 5 ml.) Add buffer ion mixture. (e.g. 5 ml. buffer 1 or 1.67 ml. buffer 2.)
3. Balancing the spectrophotometer on one of the standard solutions, obtain reading of percent transmission for the unknown.
4. Convert reading to p.p.m.
5. Calculate % Na as follows (for 3:1 dilution):

$$\% \text{ Na} : \frac{\text{p.p.m.} \times \text{dilution} \times 100}{\text{Wt. sample} \times 1,000,000}$$

$$: \frac{\text{p.p.m.} \times 200 \times 100 \times 3}{\text{Wt. sample} \times 1,000,000 \times 4}$$

A. Photometric Determination of Potassium

1. Prepare seven standard solutions containing 60, 50, 40, 30, 20, 10, and 0 (blank) p.p.m. potassium from accurate standard KCl solution of 100 p.p.m. K in the following manner:
 - (a) To 50 ml. volumetric flasks add aliquot of accurate standard. (E.G. 30 ml. for 60 p.p.m., 25 ml. for 50 p.p.m., etc.)
 - (b) To each add 4 ml. of buffer ion mixture containing:

2,000 p.p.m. Ca as CaCl_2

500 p.p.m. Mg as MgCl_2

500 p.p.m. P as H_3PO_4

250 p.p.m. Na as NaCl .
 - (c) Make up to 50 ml. with distilled water. Mix well. Stopper tightly until used.
2. Set the Beckman Model DU flame spectrophotometer to obtain 100% transmission with the solution containing 60 p.p.m. K. The following adjustments were found to be satisfactory:
 - (a) Fuel at 2.5,
 - (b) Oxygen at 10,
 - (c) Selector switch at 0.1,
 - (d) Slit width at 0.4,
 - (e) Wave length at 7710 \AA ,
 - (f) Red phototube,
 - (g) Load resistor at 3.
3. With the spectrophotometer thus adjusted and balanced on 100% transmission for the 60 p.p.m. K standard, read the percent transmission of the other six standards. Graph the percent transmission against the p.p.m. for the curve.

B. Determining unknowns.

1. From extract of nitric-perchloric acid digestion of plant material (3 grams made up to 200 ml. solution) pipette 5 ml. and transfer to a 50 ml. volumetric flask.
2. Add 4 ml. of buffer ion mixture as used in the preparation of the standards. Make up to 50 ml. with distilled water.
3. Mix well. Read percent transmission on spectrophotometer, using one of the standards to balance the machine.
4. Convert readings to p.p.m. potassium using the standard curve.
5. Calculate percentage potassium as follows:

$$\% K : \frac{\text{p.p.m.} \times \text{dilution} \times 100}{\text{Wt. sample} \times 1,000,000}$$

$$: \frac{\text{p.p.m.} \times 200 \times 10 \times 100}{\text{Wt. sample} \times 1,000,000}$$

$$: \frac{\text{p.p.m.} \times 0.2}{\text{Wt. sample}}$$

CRUDE FIBER DETERMINATION

1. Weigh out a 2-gram sample of oven dry plant material and transfer to a 600 ml. beaker.
2. Add 200 ml. of boiling 0.2518 N. H_2SO_4 and place over heat on condenser immediately.
3. Boil briskly for 30 minutes.
4. Remove and filter immediately through linen. Wash with boiling water until washings are no longer acid.
5. Wash back the charge into the original beaker with 200 ml. of boiling 0.2819 N. NaOH.
6. Place the beaker over the heat connected with condenser and boil exactly 30 minutes.
7. Remove and filter through same linen.
8. Wash with boiling water until all NaOH is removed.
9. Transfer charge by washing into crucible with 95% ethyl alcohol.
10. Evaporate alcohol on steam bath.
11. Dry crucible and contents at 110 deg. C. for about 2 hours.
Cool in dessicator and weigh.
12. Ash the contents of the crucible in an electric muffle furnace at 1,000 deg. C. for about 30 minutes. Cool and weigh. Report loss in weight as crude fiber.

$$\% \text{ crude fiber} : \frac{\text{Loss in weight} \times 100}{\text{Weight sample.}}$$

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